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DEVELOPMENT OF A SMALL ROCKET SYSTEM FOR CONDUCTIVITY MEASUREMENTS IN THE HIGH LATITUDE DISTURBED D-REGION IN SUPPORT OF ELF/VLF PROPAGATION STUDIES

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30 June 1979

Final Report for Period 9 October 1978—20 June 1979

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Measurements of the Lower Atmosphere

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

An ultra-miniature conductivity probe for small rocket applications
has been developed for measurements within the lower atmosphere (D-region
and below). The probe is contained within a MET rocket and may be launched
from standard MET sites with a minimum of personnel and equipment. The
measuring instrument is a miniature Gerdien condenser, which is ejected near
apogee and is trailed by a starute to reduce descent speeds below sonic

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20. ABSTRACT (Continued)

values. Accumulated data are transmitted via telemetry to a recording ground station.

The initial application of this instrument was at the White Sands Small Missile Range on 14 December 1978. After payload ejection near apogee data were recorded for over an hour as the instrument descended on the starute. Some modifications are indicated, but basically the concept and experiment appear sound.

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INTRODUCTION

The conductivity of the lower regions of the ionosphere, particularly during disturbed conditions, is important due to the effects upon ELF and VLF radio propagation. In this highly collisionally-dominated regime the measurement of conductivity directly by use of a Gerdien condenser [*Gerdien*, 1905] has proven useful.
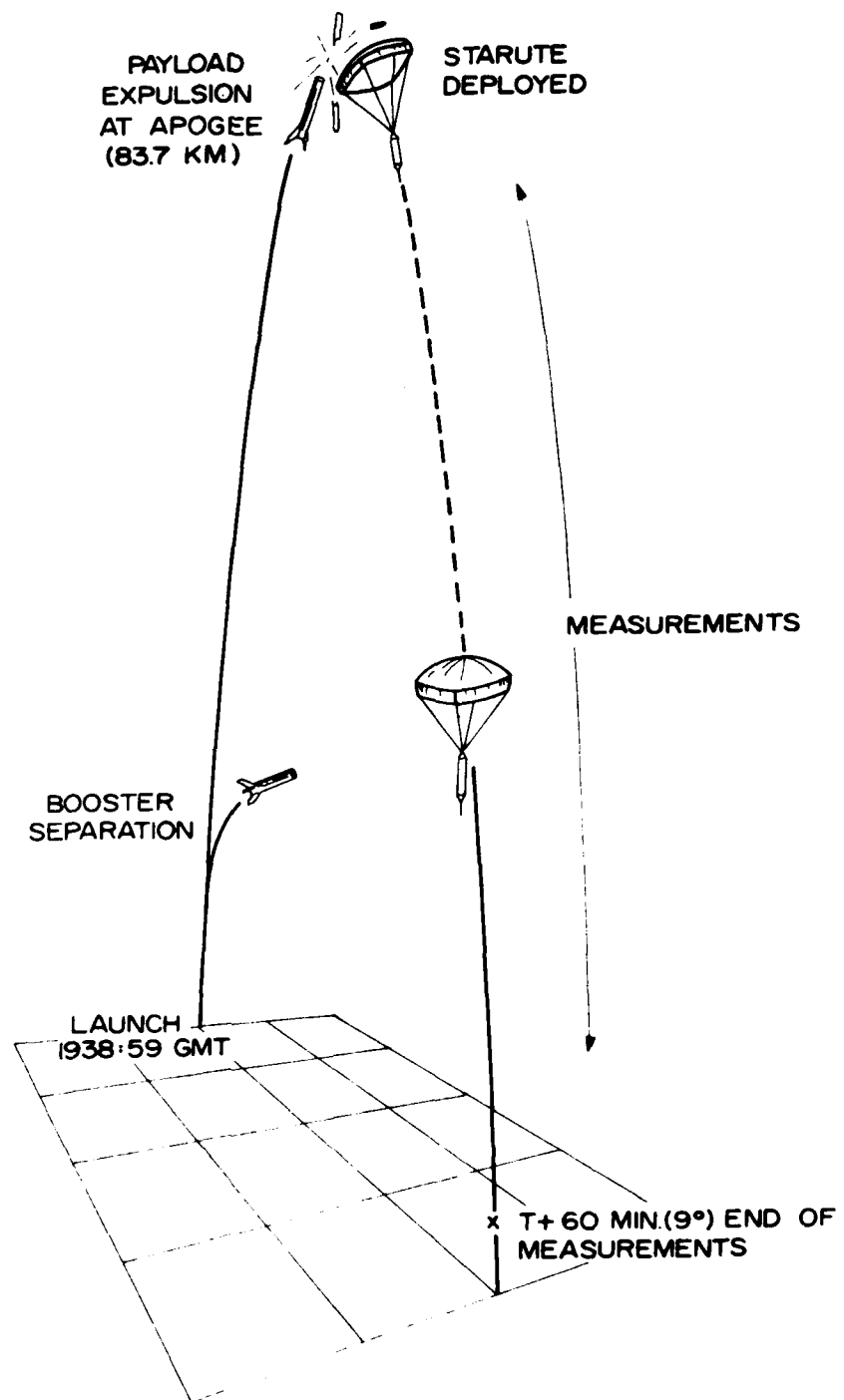
In simplest terms, this device consists of two, concentric cylinders through which the air flows and the atmospheric conductivity is determined by applying a potential across the two electrodes and monitoring the resultant current. Such instruments have been developed and used aboard rockets for measurement of atmospheric conductivity of the lower ionosphere [*Pederson*, 1965; *Burt*, 1967; *Mitchell and Hale*, 1973; *Conley*, 1974; *Widdel et al.*, 1976]. Under contract DNA001-78-C-0342, Utah State University undertook development of a miniature Gerdien condenser payload suitable for use on meteorological rocket-Dart system that was producible at minimal cost and incorporating simplicity of operation in order that launches could be effected with a minimum of field personnel. Such design criteria would provide the opportunity to utilize the instrument at remote sites such as Thule, Greenland and Andoya, Norway without the necessity for a large field party. In fact, such a simplified instrument could be left at the launch site to be launched by site personnel when desirable conditions occurred.

To accomplish these goals a modified Viper IIIA Dart vehicle configuration was developed to house the instrument and provide the measurements scenario described by Figure 1. This configuration employed a larger than normal inside diameter Dart (necessary to house the Gerdien condenser). The instrument itself was housed within the Dart portion of the vehicle and was constructed such that the complete electronics circuitry, including telemetry transmitter, is housed within the center electrode of the condenser. The instrument was ejected from the Dart at apogee along with an attached starute decelerator. The starute provided the proper axial orientation for the instrument and reduced its velocity to sub-sonic speeds, thereby simplifying

the determination of the mass rate of air flow through the condenser.

Two such payloads were designed and built, and one of these (WSMR GM-1) was launched from the White Sands Missile Range (New Mexico) on 14 December 1978 at 1238:59 (Local) to test the total concept of the experiment. The rocket and payload performed satisfactorily, achieving the desired altitude and proper deployment of the Gerdien condenser and starute. The telemetry system performed as designed and data were received for well over one hour as the payload descended on the starute. The operation of the Gerdien condenser sweep and current collection was normal throughout the flight; however, the operation was complicated by the fact that the charge neutralization of the condenser was not achieved. It was possible to derive conductivities from the measured results, but derivation of densities was not possible with any degree of accuracy since the reference potential of the Gerdien system was not known.

The remainder of this report details the theory, design, operation, and results associated with the payload and instrument, and discusses some proposed modifications that would eliminate the charge neutralization difficulties experienced.

PAYLOAD
EXPULSION
AT APOGEE
(83.7 KM)

STARUTE
DEPLOYED

MEASUREMENTS

BOOSTER
SEPARATION

LAUNCH
1938:59 GMT

x T+ 60 MIN.(9°) END OF
MEASUREMENTS

FLIGHT OF WSMR GC-1

Figure 1. Scenario of the flight of WSMR GC-1.

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INSTRUMENT OPERATION AND DESIGN

As shown in Figure 1, the Dart payload system was boosted along its trajectory with a Viper IIIA motor. This vehicle configuration is not a 2-stage motor system; the Dart portion is merely a projectile that receives its impetus from the Viper IIIA motor. All of the energy of the Dart section is imparted by the approximately 2.5 second burn of the Viper. After burnout, atmospheric drag separates the Viper motor from the Dart and the projectile simply coasts to altitude. The payload must be extremely rugged in order to survive the "G" stresses attendant to launch. Although the magnitude of these stresses is not precisely known, reports indicate that it may run to excess of 200 G's. A pyro ejection system is used to deploy the Gerdien condenser and starute from the Dart near apogee in order that the measurements can be accomplished. This ejection sequence is initiated at launch by simultaneously igniting a delay fuse which ignites a gas generator to expel the starute and Gerdien condenser package at apogee.

The measurements of ion current are translated to electrical signals and are transmitted to the ground station via a 1680 MHz transmitter. Trajectory data are obtained by radar which is able to track the payload by using the aluminized coating of the starute as a reflector.

The system was designed around the following specifications and constraints.

1. Physical Size
   (a) Maximum Gerdien Diameter: 2-3/4 inches.
   (b) Optimum Payload Length: 16 inches.
   (c) Payload Weight: under 4 lbs.
2. Electrical Power
   (a) Minimum battery lifetime: 1-1/2 hours
3. Ruggedized to survive high accelerations (>200 G's) due to booster thrust.
4. Dart Spin Rate: 20 rps.

5. Minimum Cost
   (a) Minimum field requirements so that if necessary, the
       units can be left in the field and launched by range
       personnel with a minimum of training.
   (b) Provide a highly mobile launching system that can be used
       at all MET ranges without major launcher changes or costs.

Theory of Operation

Basically, the Gerdien condenser operates by applying a sweep voltage
between the two elements of a cylindrical capacitor and measuring the
resulting current collected from the air flowing through the condenser,
as shown in Figure 2. With the polarity indicated, positive ions will be
accelerated toward and collected on the center conductor. Reversal of
the voltage allows collection of negative ions. If a plasma having positive
ions of a single species enters the cylinder at a constant velocity directed
parallel to the cylinder axis, the current as a function of applied voltage
will be as shown in the ideal characteristic curve of Figure 3. Assuming that
many collisions occur within the condenser, the voltage-current relation-
ship is linear until a voltage is reached at which all charged particles
are collected (saturation).

The slope of the initial portion of the current-voltage curve will
be proportional to the conductivity as can be seen from the expression for
current I [*Conley*, 1974]:

$$I = \sigma \frac{2\pi L}{\ln b/a} \phi_p = \sigma \frac{C}{\epsilon} \phi_p \tag{1}$$

where: σ = the conductivity

ϕ_p = the voltage across the condenser

L = condenser length

a,b = radii of inner and outer electrodes, respectively

C = the free space capacitance of the condenser
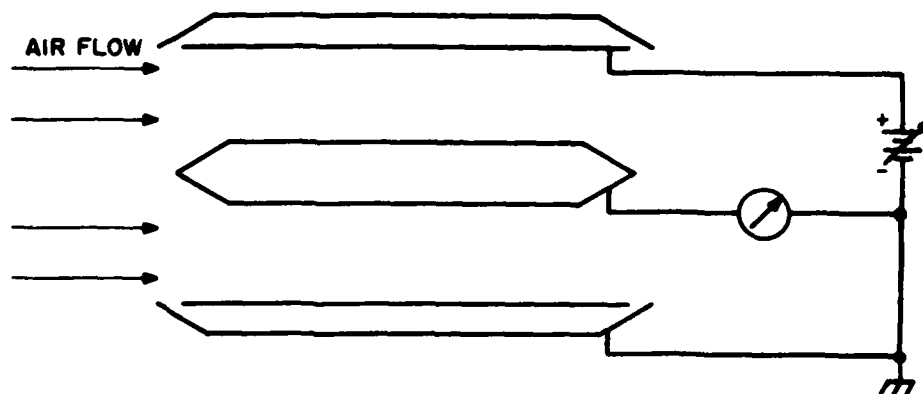
ϵ = the permitivity of free space

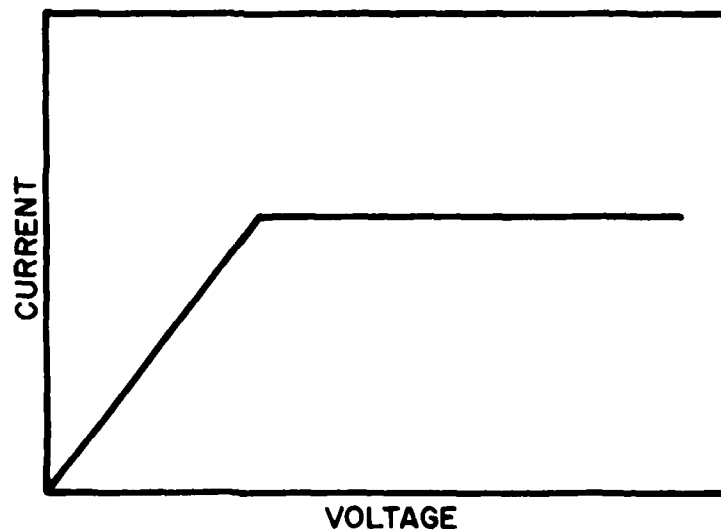Figure 2. Fundamentals of Gerdien Condenser operation.

Figure 3. Idealized characteristic curve of Gerdien Condenser.

In terms of ion mobility k, and ion density N_i, the conductivity is

$$\sigma = kN_i \, \varepsilon \tag{2}$$

The ion density can be calculated from the current in the saturation region, hence, mobility can also be derived.

The conductivity concept requiring a large number of collisions within the condenser limits the operation to the region below about 65 km, where the mean free path of any particle is much less than the distance between the two elements.

In the actual atmospheric case where more than one species of ions may be present, the curve will not have a single slope and hence, the analysis will be more complicated. The following facts, however, can be utilized:

1. The current in the saturated region will be proportional to the total ion density.

2. The initial slope of the curve will be proportional to the total ion conductivity.

3. The derivative of the curve gives information about individual ion species.

4. Ion mobilities can be derived from the ion density and conductivity results (1 and 2 above).

Mechanical Design

A special 3-inch diameter Dart to be propelled by a Viper IIIA motor was designed by Space Data Corporation as part of this program. The 3-inch Dart fixed the maximum diameter available for the Gerdien condenser as 2-3/4 inches. The physical configuration of the Gerdien condenser showing the locations of component subassemblies is shown in Figure 4. The complete electronics, including transmitter and batteries were contained inside the inner electrode. The size of batteries obtainable to power the device fixed the diameter of the inner electrode to 0.69 inches. The minimum length of the inner electrode was determined by the space required for the electronics, and the maximum length by the space available. Calculations on the sensitivity

Figure 4. Graphic portrayal of the physical configuration of the Gerdien Condenser.

and desired operating range of the instrument showed that a 15-inch long
condenser should provide reasonable current flow and that an 8-volt sweep
would be sufficient to achieve the current saturation region at the altitudes
of interest.

The final configuration of the instrument is shown in Figure 5. This
assembly was held within the Dart vehicle between two end caps with two
staves between them to provide the support to the condenser during launch
and ejection. The 14-foot starute decelerator was attached to the rear
end (opposite the antenna) by a lanyard suspending the condenser below the
starute during its descent.

Electrical Design

The electronic system of the Gerdien condenser is shown in block diagram
form in Figure 6. As shown in Figure 6, a sawtooth waveshape voltage (ranging
from -7 volts to +8.8 volts, with a repetition rate of ∿1 Hz) was applied
to the outer electrode with respect to the inner electrode. The collected
ion current flowing between these elements as a result of this voltage
was detected and converted to a proportional output voltage. The sensitivity
was set to monitor a current ranging from 10^{-10} to 10^{-7} amperes. The voltage
output from the current detector was applied directly to a voltage-controlled
oscillator (VCO) set to a center frequency of 40 KHz. A second gain range
was provided by amplifying the current detector output (by a factor of 10)
and modulating a 22 Hz VCO. The outputs of the two subcarrier oscillators
were linearly mixed at the input of the telemetry transmitter to frequency
modulate the transmitter. The transmitter was a self-excited strip line
oscillator operating at 1680 MHz with an output power of 200 mw.

The power for the instrument was provided by seven-1/2 AA Lithium
primary batteries which together produced +18.5 volts. The required negative
voltage was generated from the +18.5V source with a simple low-power inverter.

In operation, the instrument was turned on simply by inserting the
batteries and screwing on the end cap. After instrument turn-on, the bat-
teries provided at least 1-1/2 hours of operation.

Figure 7 is a schematic diagram of the Gerdien condenser circuitry.
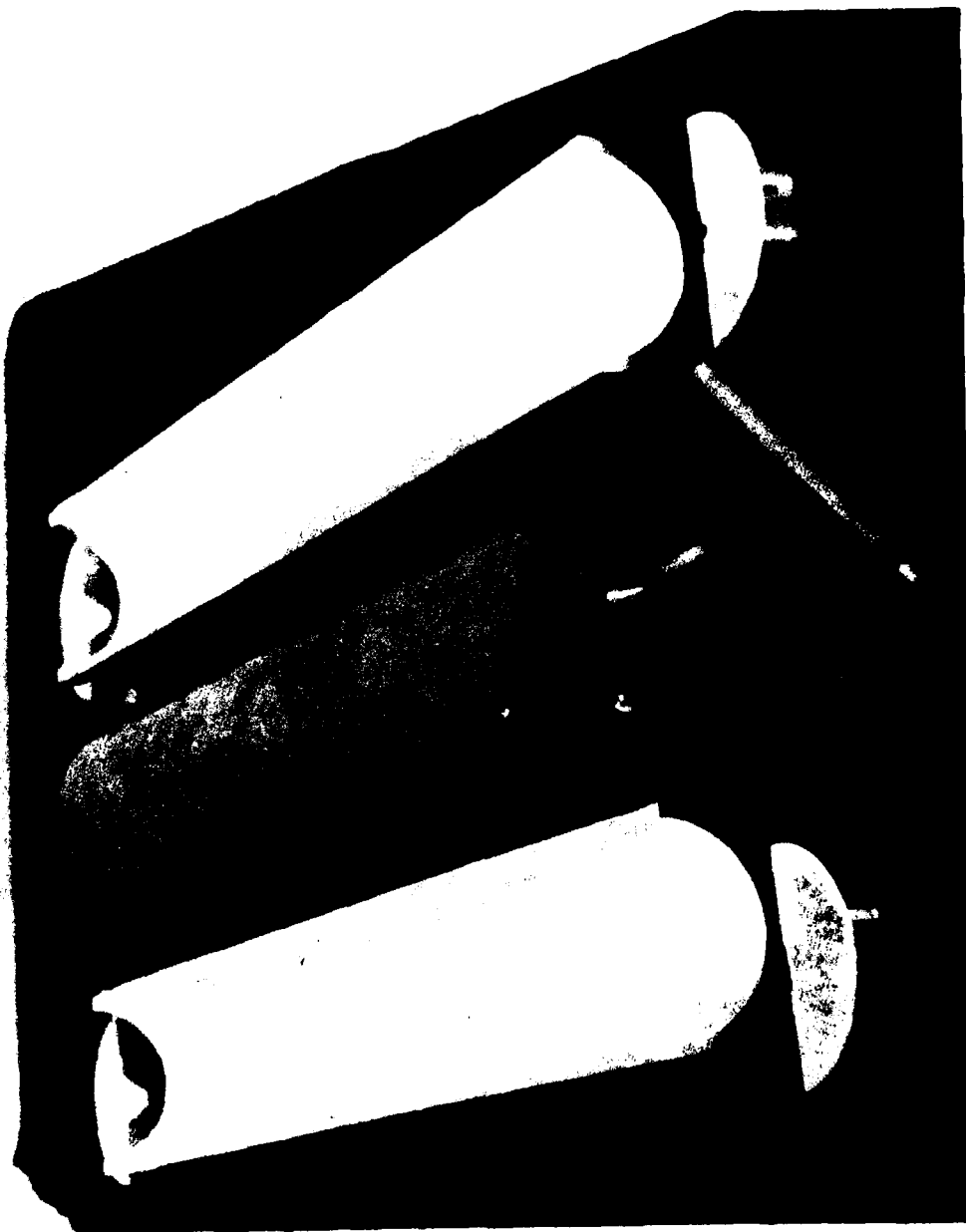
Figure 5. A photograph of the Gerdien Condenser, also showing staves and end caps.
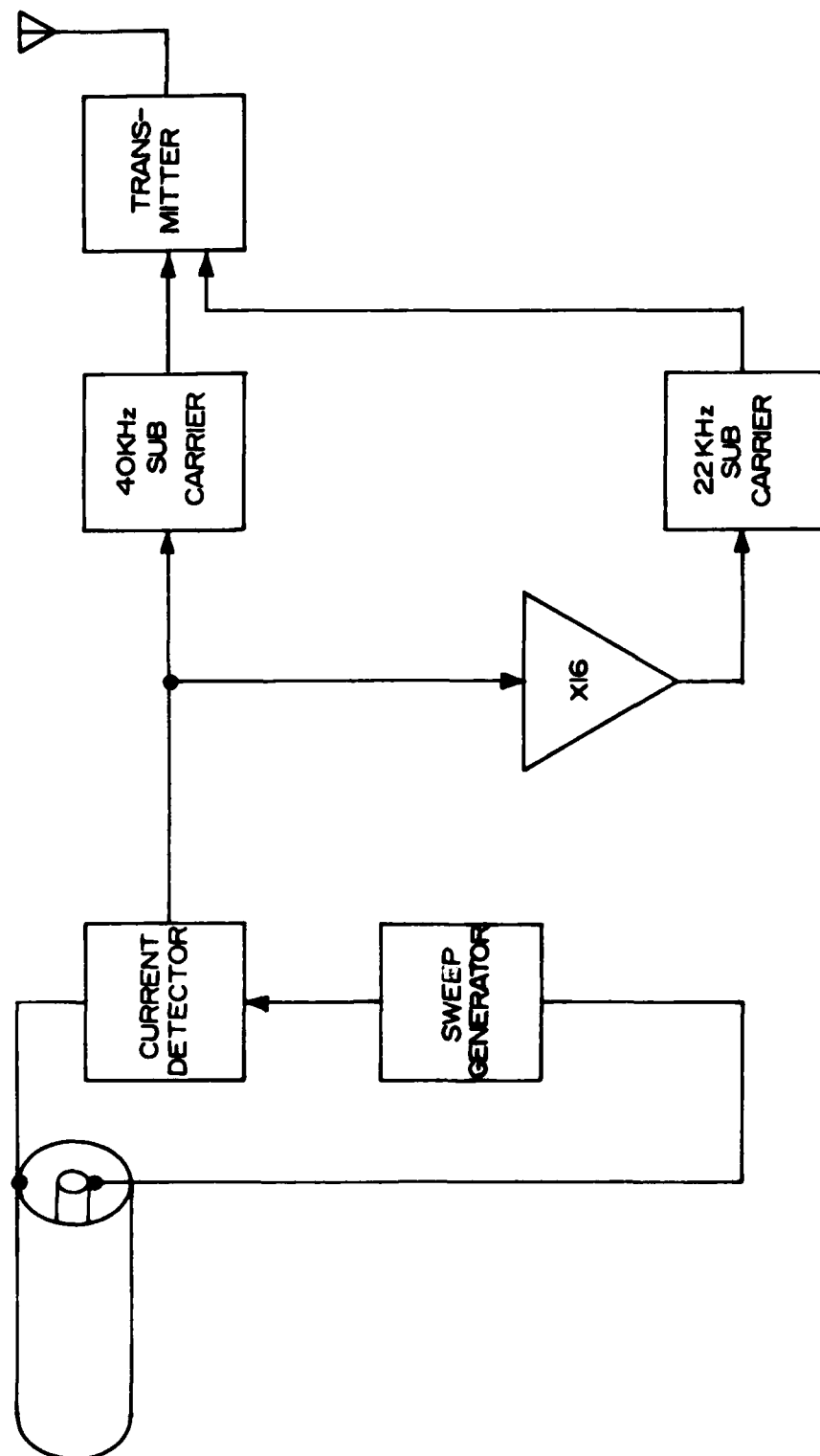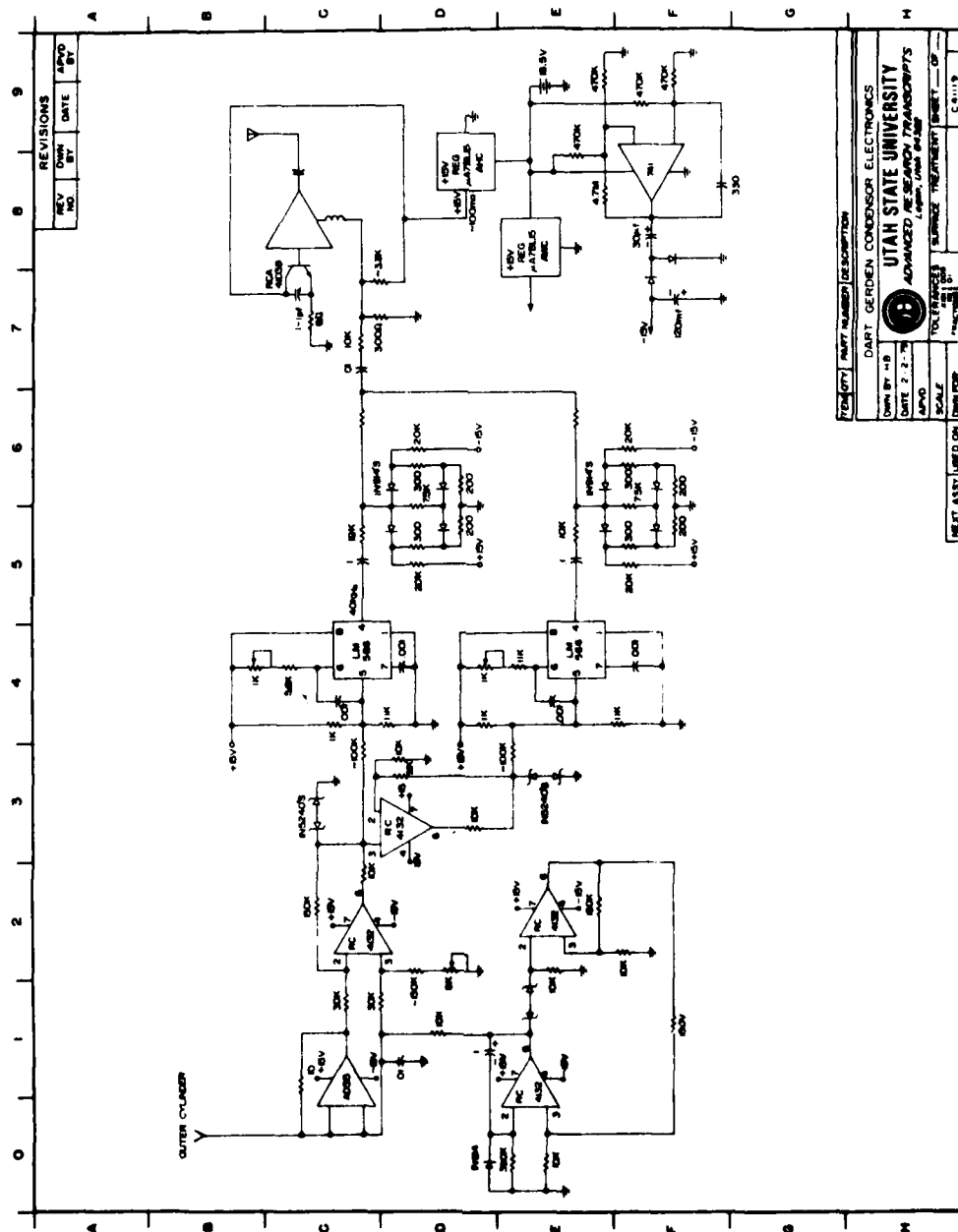
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Figure 6. A block diagram of the Gerdien Condenser and telemetry circuitry.

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Figure 7. Schematic diagram of Gerdien Condensor electronics.

Launch Configuration

The launcher employed to fly the Viper IIIA-Dart (WSMR GC-1) was a standard Super Loki pedestal with a straight rail in place of the spiral rail. This straight rail was necessary to accommodate the Dart which incorporates a larger fixed tail than the standard MET system Darts. Launch crews at the standard MET sites are familiar with the Super Loki systems and it is felt that with minimal instruction they would be able to satisfactorily load, arm and launch the Viper IIIA-Dart configuration.

RESULTS

The initial flight of this payload design was successfully accomplished from the White Sands Small Missile Range, New Mexico on 14 December 1978. The vehicle was launched at 1938:59 (GMT) and attained an apogee of 83.7 km with a ground range of 14.1 km on a 356.6° azimuth. Those flight parameters match an effective launch elevation (QE) of 85.2°. The actual launcher settings were 80.9° QE and 348° azimuth. Launches are not wind weighted on the Small Missile Range, so the amount of dispersion due to winds and that due to the vehicle itself are not known. One important factor related to dispersion was noted however; the booster was stable (as it was during the October 1978 test firing of the vehicle only), so no problems are anticipated with booster impacts. The performance data from this flight indicate that an altitude of approximately 68.5 km would be achievable for a launch from sea level.

The instrument and starute separated satisfactorily at apogee and descent required more than an hour. Data were recorded for a period of 1/2 hour on a prime recorder and continued on a secondary recorder (discriminated data only) until T+1 hour at which time the payload was still at an elevation of 9°. Recordings were not continued past the T+60 minute point since range equipment was necessarily diverted to support another launch. Throughout the total recording period good telemetry signals were received with very little dropout.

Figure 8 is an example of the data obtained from the Gerdien at an altitude of ∿67 km. Two slopes are obvious for the positive ion region,
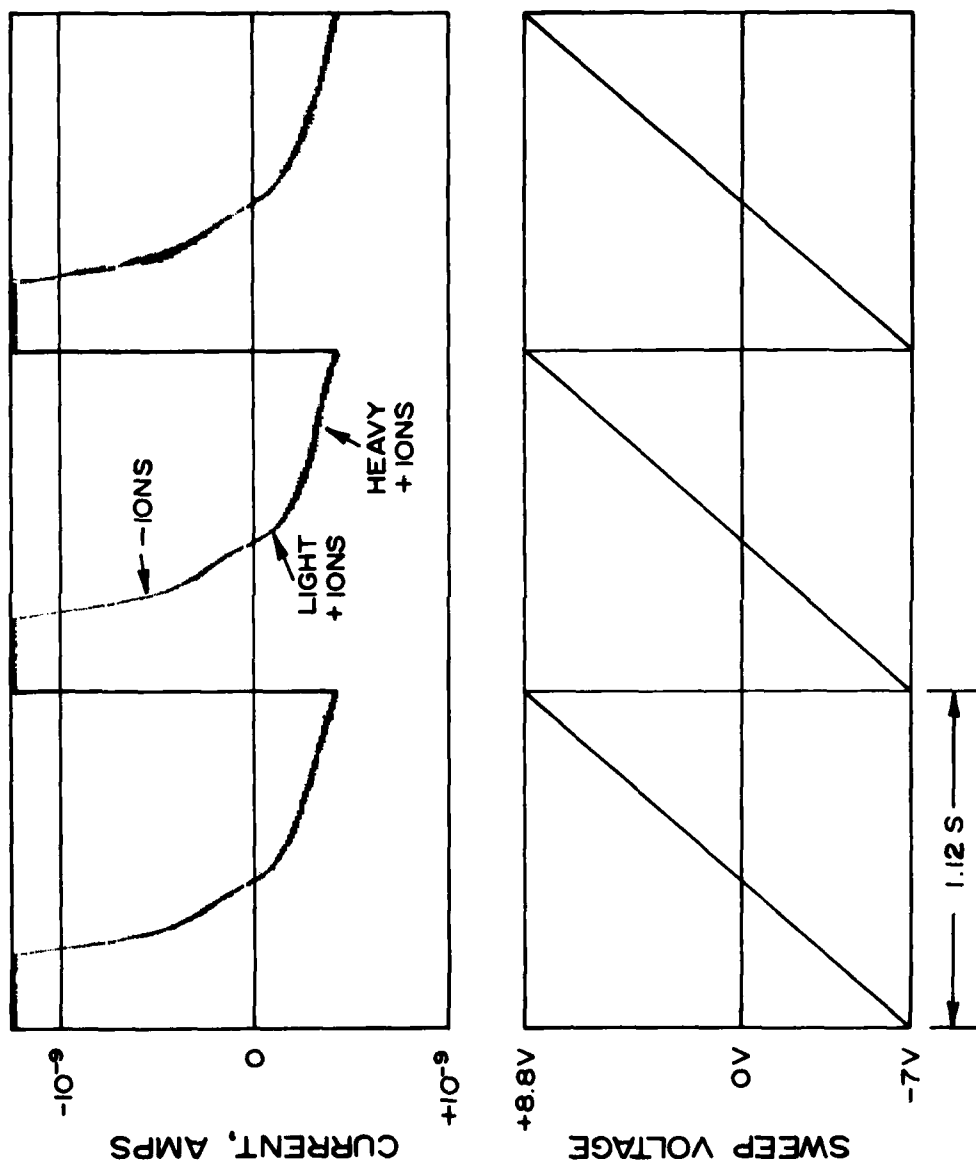
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Figure 8. Example of telemetry record of Gerdien current (upper trace) with the voltage sweep shown in the lower trace. The upper portion of the current corresponds to negative ion collection (-ions) and the lower to positive ions. The break in the positive ion slope indicates two different ions (light and heavy ions).

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indicating the measurement of ions of two vastly different mobilities. The measurements of light and heavy ions at this altitude have been measured by *Rose and Widdel* [1972] and indicate that the mobility of the light ions is about an order of magnitude higher than that for the heavy ions.

The conductivities calculated from Equation 1 from the curve measured at this altitude are 3.2×10^{-12} mhos/cm for positive ions and about 10^{-11} for negative ions with the heavy ions giving about 2.7×10^{-13} mhos/cm. The positive ion conductivity is plotted every 10 km in Figure 9 along with a comparison with measurements of conductivity determined with the Gerdien condenser by *Widdel et al.*, [1977] and the average blunt probe results of *Hale et al.* [1978]. Except for the 40 km point, the results of this flight are consistent with those of the other workers.

CONCLUSIONS AND RECOMMENDATIONS

The 14 December flight of the Viper Dart Gerdien condenser payload proved the validity of the basic approach. The larger Dart package with the Gerdien condenser achieved a satisfactory altitude (84 km) which leads to a predicted 68 km for a sea level launch. The starute and Gerdien package ejected and descended as desired and a solid telemetry record was achieved. The Gerdien package survived the rigors of launch, electronically performed as designed and data were accumulated on ion conductivities that compare favorably with results from other workers. One difficulty encountered in the flight was the inadequate neutralization of collected charge so that the actual voltage of the reference with respect to the plasma was not known.

The improvements in the Gerdien condenser system that are being incorporated into the modified design are (1) the addition of a charge neutralizer on the aft end of the condenser; (2) use of guard rings on the ends of the condenser to minimize stray electric fields; (3) and investigation of the incorporation of a 400 MHz transponder in the instrument package to provide tracking of the payload at remote sites where no radar facilities are available.
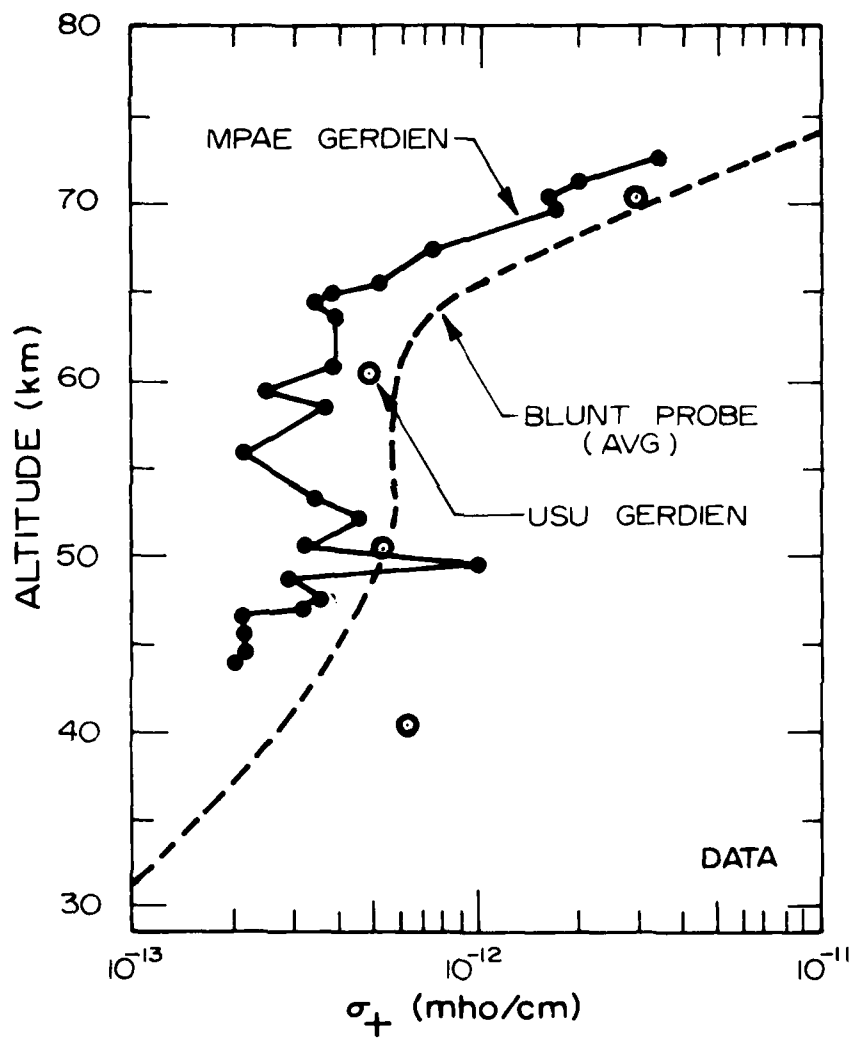
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Figure 9. Positive ion conductivity from the Utah State
University (USU) Gerdien condenser compared with
Gerdien condenser measurements (MPAE) of *Widdel
et al.* [1977] and average blunt probe results of
Hale et al. [1978].

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